LASERNET FINES Optical Oil Debris Monitor

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Abstract: The performance characteristics of the LASERNET FINES optical oil debris monitor are described. This monitor provides on-site measurements of particle size distributions and shape characteristics in lubricating, hydraulic and other fluids. It will provide information on mechanical wear of oil wetted machinery components and contamination in hydraulic systems. The features and capabilities of a portable instrument based on LASERNET FINES are described.

Key Words: Bearings; catastrophic failure; early warning; gears; hydraulic fluid; real-time; shape classification; wear debris

Introduction: LASERNET FINES is an optical oil debris monitor that is designed to provide real time measurements of size distributions and shape characteristics of particles in fluids in the size range from about 5 to 100 micrometers [1-5]. It will provide information on type, severity and rate of progression of specific faults and wear conditions in mechanical systems based on measurements of size distribution, shape and rate of production of debris particles [6-9]. This capability allows distinction of debris particles arising from different types of faults to be made and the progression of different

specific faults to be monitored. It will also provide information on particulate contamination in hydraulic, fuel and other fluid systems.

The basic concept of LASERNET FINES is illustrated in Fig. 1. The system uses a flowing fluid column that is back-illuminated with a pulsed single-spatial-mode laser diode to freeze the fluid motion. The light transmitted through the fluid is magnified and imaged onto a CCD camera. Some of the advantages of this technique are that flow speed does not have to be controlled other than being fast enough to clear the viewing area between laser pulses, and multiple particles in a single frame can be analyzed without confusion. The images obtained with the CCD camera are processed to identify individual objects. The objects are analyzed for size and various shape characteristics such as aspect ratio, circularity and edge roughness. The number and size of particles greater than about 5 micrometers and the shape characteristics of particles larger than about 20 micrometers are determined. The shape characteristics are used to classify the particles into mechanical wear classes such as cutting, sliding and fatigue with a neural net shape classifier. Each laser pulse provides a single image frame to be analyzed and the results of multiple frames are combined to form a complete record for the sample under study.

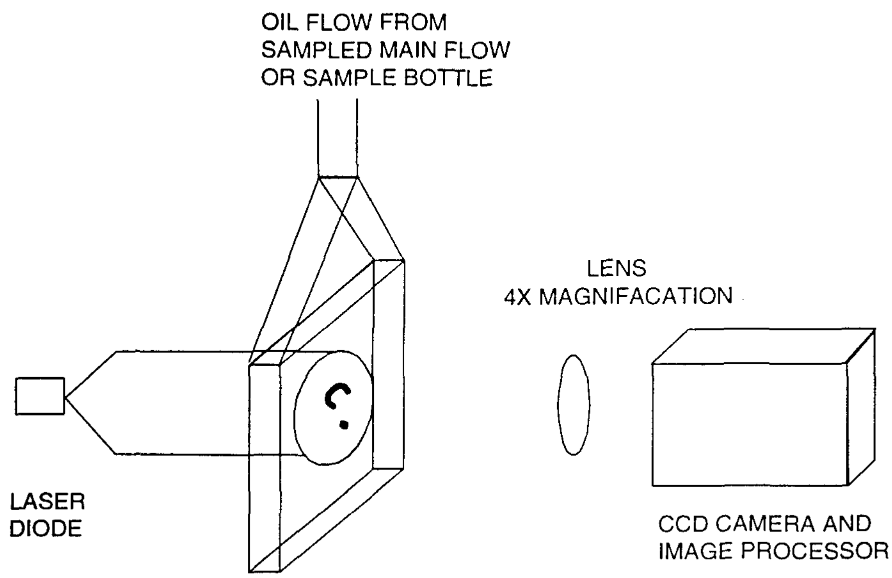

Figure 1. Schematic diagram of LASERNET FINES

LASERNET FINES can be configured as a batch processor, in which samples drawn from the machinery are analyzed off-line, as a temporary on-line unit or a dedicated on-line unit. The batch processor is appropriate for use in applications in which many different types of machinery are to be analyzed with one unit. It can eliminate the long turn around time associated with remote laboratory analysis. The temporary on-line unit is appropriate for use with problem equipment or for fleet utilization. The permanent on-line unit can provide continuous, autonomous monitoring that can provide early warning

and trending information for identifying fault progression and contribute to condition based maintenance and reduced manpower situations.

LASERNET FINES is being developed under the Condition Based Maintenance Program of the Office of Naval Research (ONR) by a team involving Naval Research Laboratory, Lockheed Martin Tactical Defense systems and Predict/DLI. The basic technology capabilities are being developed at NRL, while Lockheed Martin and Predict/DLI are producing a portable batch processor for field applications based on the LASERNET FINES technology under contract to ONR.

Technology Development: The initial efforts at NRL have been directed at demonstrating the basic technology in a batch processor format. The unit consists of a collimated single-spatial laser diode, a flow cell, 4X magnification imaging optics, progressive scan camera, and computer with frame grabber. The laser diode operates at 820 nm with a peak power of 27 mW. The laser is pulsed with a duration between 5 and 350 μs depending upon the transparancy of the fluid being analyzed. The flow cell is approximately 100 μm thick with a fluid reservoir mounted above the cell. Fluid is drawn through the flow cell with a peristaltic pump. Before a sample is analyzed, the fluid is shaken for 30 seconds to disperse the particles and is then placed in an ultrasonic bath for 45 seconds to remove trapped air bubbles. This preparation method has been observed to give consistent results over several identical samples. The imaging optics relay a 1.6 mm x 1.2 mm area of the flow cell flow onto the CCD camera at a 4X magnification with a spatial resolution of about 2.5 micrometers. The images are transferred to a computer and are analyzed at a rate of 7 frames per second.

The images undergo a pixel-by-pixel subtraction of a background image and are thresholded. The thresholded image is scanned in a raster format following the method of Capson (10) to identify particle objects. The particles are analyzed to determine the following features: maximum diameter and area for all objects, and aspect ratio (defined as area / maximum diameter ^2), perimeter, and circularity for particles greater than 20 μm in diameter.

The particles are classified into fatigue, sliding and cutting wear using a linear vector quantization neural net and specific shape features. The classifier was trained with a set of wear particles images of known origin that were provided by Predict/DLI and by University of Swansea, Wales, UK. The classifier had about a 90% success rate in placing the particles from the training set into the correct wear category.

The LASERNET FINES bench unit was used to examine several different types of fluid that are expected to be encountered in shipboard machinery. We present below results obtained for hydraulic calibration fluid, obtained from Fluid Technologies, Inc., and for MIL-L-9000 diesel lubricant. The results of the measurements of the concentration of particles in the hydraulic calibration fluid are shown in Fig. 2. The distribution of particle concentration is shown as a function of maximum linear dimension in NAS size bins (5-15 μm, 15-25 μm, 25-50 μm, > 50 μm) for two runs with the LASERNET FINES unit,

along with the concentrations given by FTI. The agreement is quite good for the smaller three bins, with larger deviations seen in the largest bin, which are likely due to statistical fluctuations because of the small number of large particles in the samples.

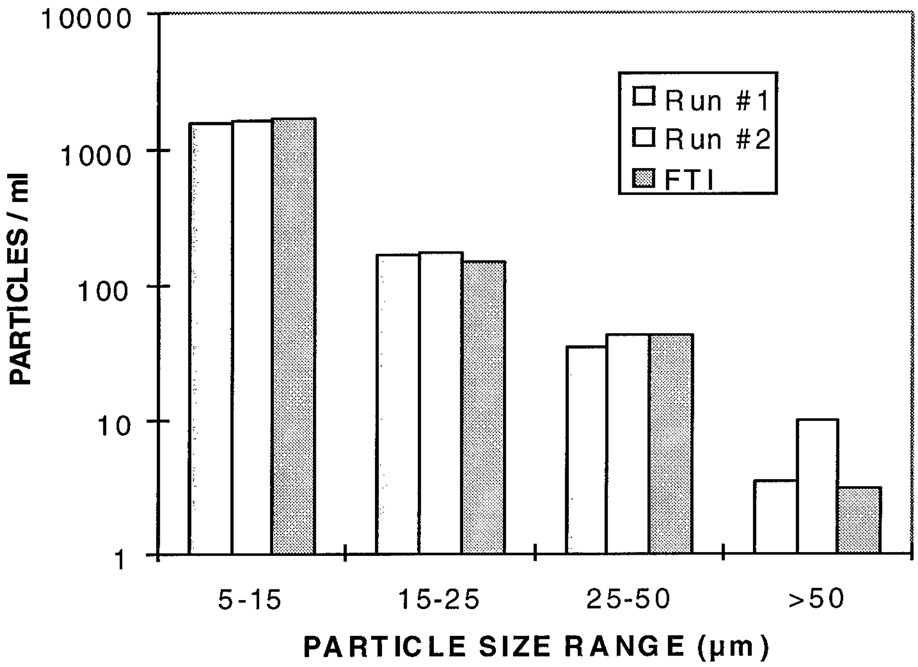

Figure 2. Measured particle distribution for two runs by LASERNET FINES instrument compared to particle distribution provided by Fluid Technologies Inc. Measured sample volumes are: 2.25 ml for Run 1, 1.5 ml for Run 2.

Several samples of MIL-L-9000 from equipment aboard the USS Gunston Hall were also analyzed, with the results shown in Fig. 3. The transmissivity of these samples in our viewing cell varied over 3 orders of magnitude, from 80% to less than 0.001%. These results show a consistently large concentrations of particles in the size range from 5-15 μm, with considerable variability of concentration in the larger size ranges. Correlation of these results with other analysis techniques is in progress.

Instrument Development: Under a contract with the Office of Naval Research (ONR), Lockheed Martin Tactical Defense Systems – Akron has developed a batch instrument based on the LASERNET FINES technology to analyze fluid samples for the wear debris particles. A photograph of the instrument is shown in Fig. 4. The instrument was designed to fit the Navy's need for a shipboard system which analyzes wear debris to help determine machine condition. The instrument analyzes particles in the size range of 5 to 100 microns and produces a statistically accurate result in 7 minutes. It counts and calculates size trends for particles based on size over the complete size range. Using a neural net classifier, it also identifies particles by wear type in the size range of 20 to 100

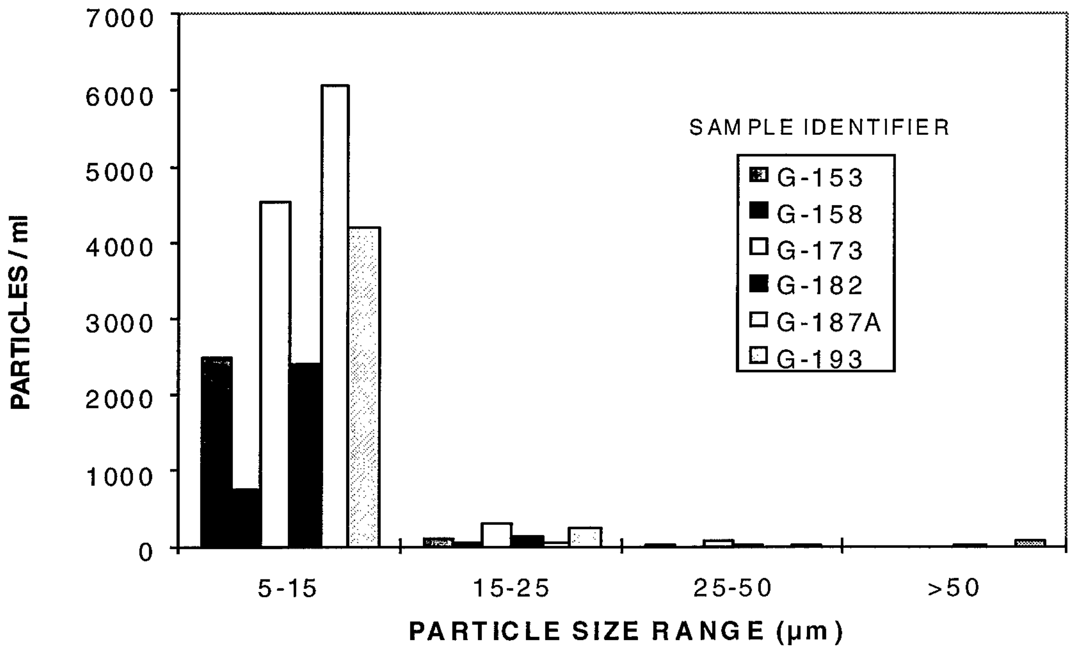

Figure 3. Particle size distribution for several samples of MIL-L-9000 diesel lubricant

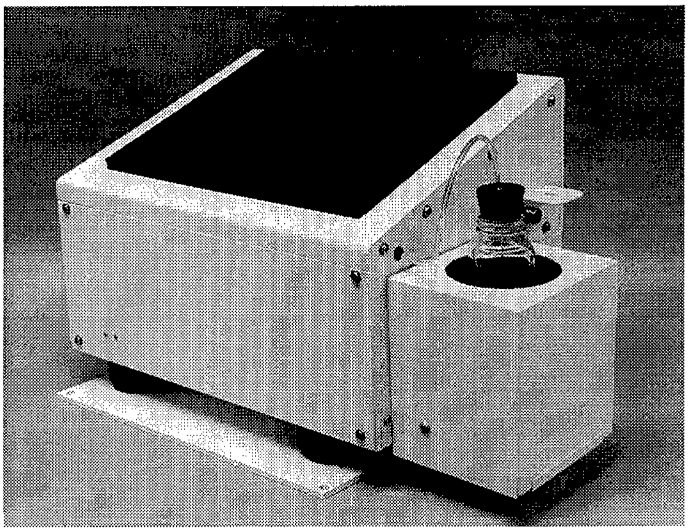

Figure 4. Photograph of Lockheed Martin Optical Oil Debris Monitor

microns. Three classes of particles are identified: fatigue, severe sliding wear, and cutting wear. Based upon the information gathered on particle concentration, sizes, trends, and types, a machine condition can be determined.

Figure 5 shows the basic functions of the system. Fluids are processed in batches. Fluid from a sample bottle is drawn into the instrument using a sipper arrangement and a peristaltic pump. The fluid is pumped through an optically transparent flow cell. Coherent light from a pulsed laser diode is used to back-illuminate the sample, while a CCD camera with macro focusing optics images the sample 30 times per second. A Pentium-based processor with a frame grabber card digitizes the resulting images and performs all processing functions. The results are displayed on a color LCD display with touch panel interface.

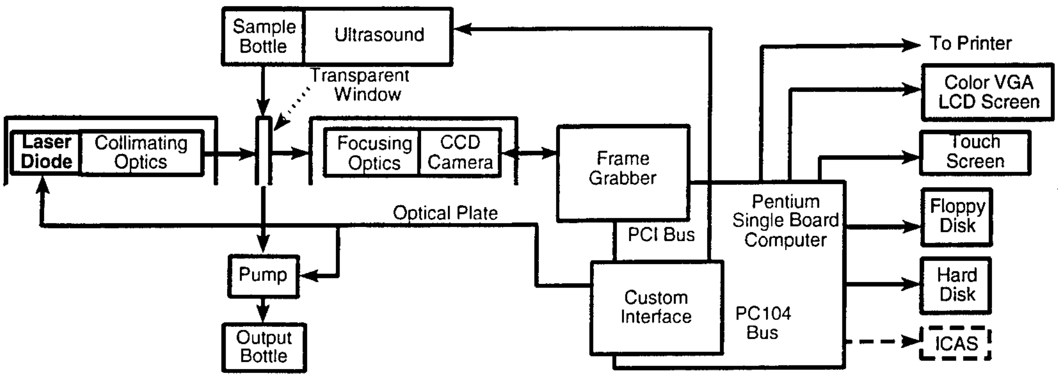

Figure 5. Block diagram of the Lockheed Martin Optical Oil Debris Monitor

The instrument was designed to be compatible with shipboard operation. It requires 110 VAC 60Hz power. Its volume is about 1 ¼" cubic feet and it weighs about 35 pounds. To help protect the unit from external shock and vibration, the unit is isolated from the base plate with shock mounts.

The instrument was designed to interface with a centralized computer system such as the Integrated Condition Assessment system (ICAS) that is available aboard some US Navy ships. The physical interface used is a 10 Mbit/sec Ethernet. Using the Windows network file system protocol, information is passed to the ICAS by writing a series of files to a directory mounted on the ICAS system. This data is transferred to ICAS after every oil test is performed and includes information on the results of the test as well as information on the machine under test and where the sample was taken.

In the design of this instrument special emphasis was given to the user interface. A graphical user interface based upon a series of about 30 context specific menus was developed to guide a user through the various functions that can be performed. A touch screen over the color LCD display is used for input of information into the system. The touch screen used in conjunction with the menuing system simplifies the input process by guiding the user's choices at each stage of the process. The graphical user interface is based upon Windows NT's windowing environment. When possible, the user is presented with scrolling lists of options to choose from. Most data fields have up/down buttons for incrementing or decrementing through values. When specific fields of data

need to be entered, the user is guided through the process by the computer highlighting the specific fields in the color, yellow. In the case, when the standard set of slide bars, and scrolls lists are not of the appropriate form for receiving data from a user, a standard keyboard is presented on the display for use. In these situations, before it is presented, a list of past inputs is presented for use. Only if this past data is not appropriate, will a keyboard be presented. A picture of the starting menu screen is shown in Fig. 6, while a picture of one of several results screens is shown in Fig. 7.

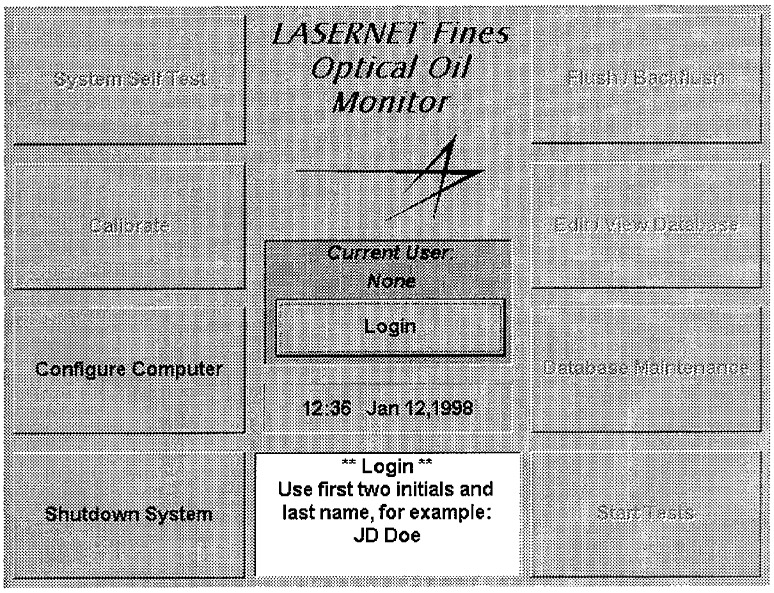

Figure 6 Example of the startup screen from the user interface, showing user options for running sample tests or other operations.

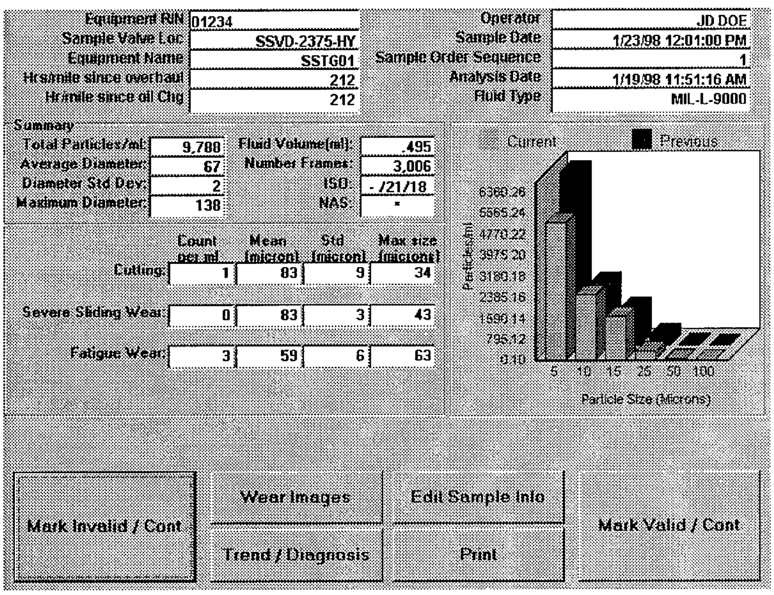

Figure 7. Example of one of the results screens showing the type of information provided.

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